Journal of Information Engineering and Applications
ISSN 2224-5782 (print) ISSN 2225-0506 (online)
Vol.4, No.10, 2014

Power Line Communication (PLC) Impulsive Noise Mitigation: A Review

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Abstract

Power Line Communication (PLC) is a technology which transforms the power line into pathways for the conveyance of broadband data. It has the advantage for it can avoid new installation since the current installation used for electrical power can also be used for data transmission. However, this power line channel presents a harsh environment for data transmission owing to the challenges of impulsive noise, high attenuation, selective fading and etc. Impulsive noise poses a severe challenge as its Power Spectral Density (PSD) is between 10–15dB above background noise. For good performance of the PLC system, this noise must be mitigated. This paper presents a review of the techniques for the mitigation of impulsive noise in PLC which is classified into four categories, namely time domain, time/frequency domain, error correction code and other techniques. Time domain technique is a memoryless nonlinear technique where the signal's amplitude only changes according to a specified threshold without changing the phase. Mitigation of impulsive noise is carried out on the received time domain signal before the demodulation FFT operation of the OFDM. Time/Frequency technique is a method of mitigating impulsive noise on the received signal at both before FFT demodulation and after FFT demodulation of the OFDM system. Error correction code technique is the application of forward error correction code by adding redundancy bits to the useful data bits for detection and possibly correction of error occurring during transmission. Identifying the best performing technique will enhance the deployment of the technique while exploring the PLC channel capacity enhancement in the future. The best performing scheme in each of the category were selected and their BER vs SNR curves were compared with respect to the impulsive noise + awgn curve. Amongst all of these techniques, the error correction code technique had a performance that presents almost an outright elimination of impulsive noise in power line channel.

Keywords: Impulsive noise, time domain, time/frequency domain, error correction code, sparse Bayesian learning, recursive detection and modified PLC-DMT**.**

1.0 Introduction

The demand for broadband in education, health, entertainment, gaming, advertising, business and home networking has increased tremendously over the years. A broadband access network includes wired line, wireless and satellite. In wired line network, new installation of cables such as coaxial, UTP Cat-5, UTP Cat-6 and optic fiber are required and devices are plugged directly into a modem or router for broadband access, this is referred to as wired LAN.

The ever increasing demand for broadband leads to the consideration of transmitting broadband data on power line network.

Power Line Communication (PLC) is a technology saddled with the responsibility of transforming the standard electric power network into a communication pathway. Hence narrowband/broadband information can be transmitted over its entire length to every device in use on the grid/network and to every user outlet(Yousuf, Rizvi, Arabia, & El-shafei, 2007). It is the technology implementing the existing house wiring to provide broadband internet access. Thus, high-speed internet access points are achieved of every electrical outlet in the house. New cable installation is therefore not necessary.

PLC can assume two types of architecture; narrowband and broadband architectures (Korki, Hosseinzadeh, Vu, Moazzeni, & Foh, 2011). Narrowband PLC frequency spectrum is from 3 to 148.5 KHz in Europe and can be above 500 KHz in the US. Its data rate is in Kbps over a maximum distance of 1 Km, (Katayama, Yamazato, & Okada, 2006). Broadband PLC has a wider spectrum spanning from 1 to 30 MHz, thus, 1-15 MHz for outdoor applications and 15-30 MHz for indoor applications. Its data rate is 300 Mbps, (Korki et al., 2011).

The high-speed PLC architectures use modulation schemes such as Gaussian Minimum Shift Keying (GMSK), Direct Sequence Spread Spectrum (DSSS), and Orthogonal Frequency Division Multiplexing (OFDM). OFDM is adopted, owing to its robustness to selective fading multipath and different kinds of interference (Tsakiris, Salis, & Uzunoglu, 2009).

Power line network poses a hostile channel to communication signals since they were designed only for electric power at frequency of 50 Hz or 60 Hz. So power line network has characteristics of selective fading, multipath, noise and attenuation on broadband data. These characteristics haphazardly affect the performance of the PLC (Yousuf et al., 2007), (Katayama et al., 2006), (Korki et al., 2011).

This paper focuses on the noise issues.

These noises, which militates against the performance of the PLC, can be classified into three categories with sub-classification in the category (Cort, Luis, & Ca, 2009) , (Guillet, Lamarque, & Ravier, 2009).

These categories as depicted in figure 1 includes; periodic impulsive noise synchronous with the mains frequency, periodic impulsive noise asynchronous with the mains frequency, asynchronous impulse noise, narrowband interferences are caused by sinusoidal or modulated signals coupled via radiation and their levels usually vary with daytime and the summation of all the noise types that does not fall in the above categories is called background noise.

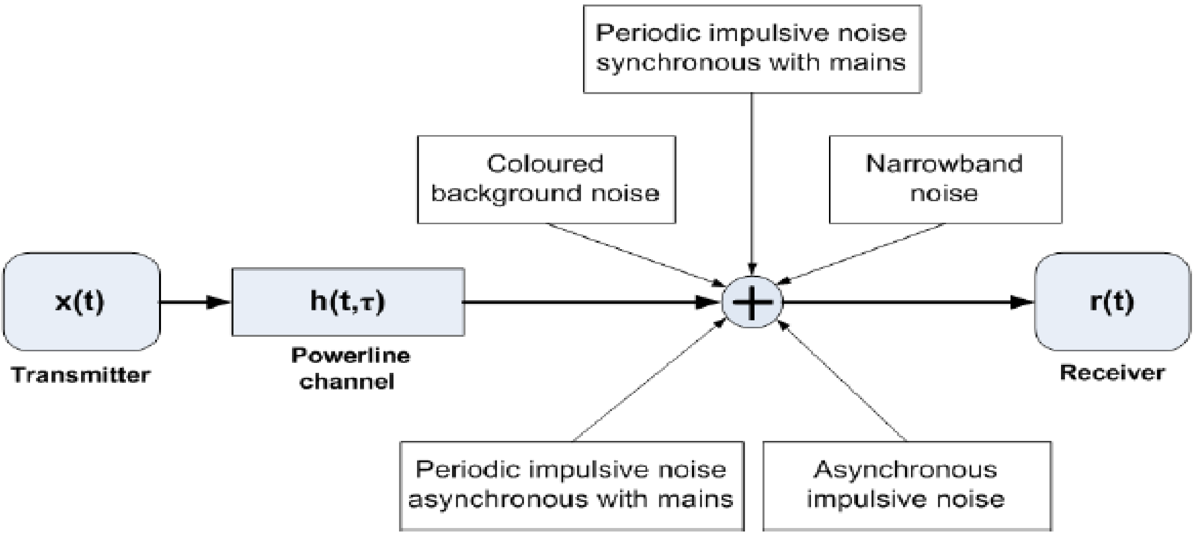


Figure 1 Power line channel noise scenario

The impulsive noise has pulse duration of microseconds to milliseconds with random arrivals. Its PSD is almost about 50dB above the background noise. Owing to this characteristic, the impulsive noise poses the most severe impairment, as it can contaminate/corrupt to a large extent the burst of transmitted information.

The paper is a review of the performance of various techniques used in mitigating impulsive noise in PLC. The different techniques were classified into four groups, namely; time domain, time/frequency domain, error correction code and other techniques. Each of these techniques reduces the effect of impulsive noise on the PLC performance.

The paper is organized as follows; a general overview of PLC is given in section 1. Section 2 describes the characteristic of impulsive noise in PLC. The importance of mitigating this noise in PLC is presented in section 3. Various techniques deployed in the mitigation of this noise in PLC is grouped into four categories and described in section 4. The best performed method in each of the techniques was compared in section 5. Conclusion was drawn in section 6.

2.0 Overview of PLC

PLC can be referred to as Power Line Carrier, Power Line Digital Subscriber Line, Mains Communications, Power Line Telecom, Power Line Networking and Broadband over power Line.

In PLC, no more wire is required as existing wire is implemented, users can just plug in receivers in any outlet on the installation, internet connection can be shared, computer or appliances can be moved as desired, there is ease in installation and use of data encryption, security is provided and both power and communication needs offered by one wire.

A typical Power line network has three voltage levels, High Voltage (HV), Medium Voltage (MV), and Low Voltage (LV) levels respectively.

It also comprises of three sections, namely, Generation, transmission and distribution.

The process of PLC entails the conversion of communication signal into a form that will permit its transmission through electrical network. Two devices are majorly responsible for this task. They are PLC Modem and PLC Base Station.

Connection of the standard communication used by the subscriber to the power line transmission medium, for the purpose of carrying out modulation and coding (MAC and LLC) is provided by the PLC Modem.

The PLC access system is connected to its backbone network and provision of multiple network communication interfaces for connection with a high-speed network is the sole responsibility of the PLC Base Station

Several other devices are used in the PLC towards achieving effective and efficient system.

Couplers, these are high-pass filters, implemented to separate the communication signals above 9kHz from the electrical power (50Hz or 60Hz) and to ensuring safe galvanic separation. To ensure that longer network distance in LV network is possible, Repeaters are incorporated. It also functions to partition the PLC access network into several network segments by using different frequency bands or time slots. Gateways provide distinction between a PLC access network and an in-home PLC network. It can be placed anywhere in the PLC access network.

All these components are connected as shown in Figure 2 to form the PLC architecture schematics.

For the susceptibility of the HV lines (often referred to as Backbone) to interference and attenuation, they are not suitable for data transmission, instead fiber optic cables are often installed along high voltage routes for some applications.

MV lines (often referred to as Middle mile), owing to their characteristics, i.e. smaller voltage levels and the nature of their medium, they form the backbone of electric utility data communication over power lines. The LV line (Last mile) is the network that the PLC technology uses in deploring communication services to the home or office as well as putting in place the in-building networking via power lines.

There are basically two applications of PLC; Power Line Outdoors Telecoms and Power Line In-door Telecoms.

Power Line Out-door Telecoms involves Automatic Meter Reading (AMR). Power meter reading which uses power-grid from homes to substation, works over the medium voltage (10 kV), at a low-level speed data rate of 600 bps – 2.4 kbps.

Power Line In-door Telecoms involves data communication in a local area (home). It uses house power grid and works over the Low Voltage (110 – 240) with a data rate of 14 – 45 Mbps.

3.0 Impulsive noise in PLC

Noise in PLC can be modeled by using Middleton's class A noise model. Two types of noise, background and impulsive noises are visible in this model. The background noise follows Gaussian distribution, while the impulsive noise is a noise that arrived according to Poisson distributed random sequence. Analysis of the effects from these noises on OFDM-based PLC system shows that the background noise can be modeled as AWGN with zero mean and variance σ_w^2, and the impulsive noise (i_k) is given by (K. S. Al-mawali, Sadik, Hussain, & System, 2009):

$$i_k = b_k g_k \tag{1}$$

where b_k is the Poisson process designating the arrival of impulsive noise and g_k is the white Gaussian process with zero mean and variance, σ_w^2. The Poisson distribution of the impulsive noise is at a rate of ⋏ units per second, giving a probability of event of k arrivals, $p(k)$ in seconds by

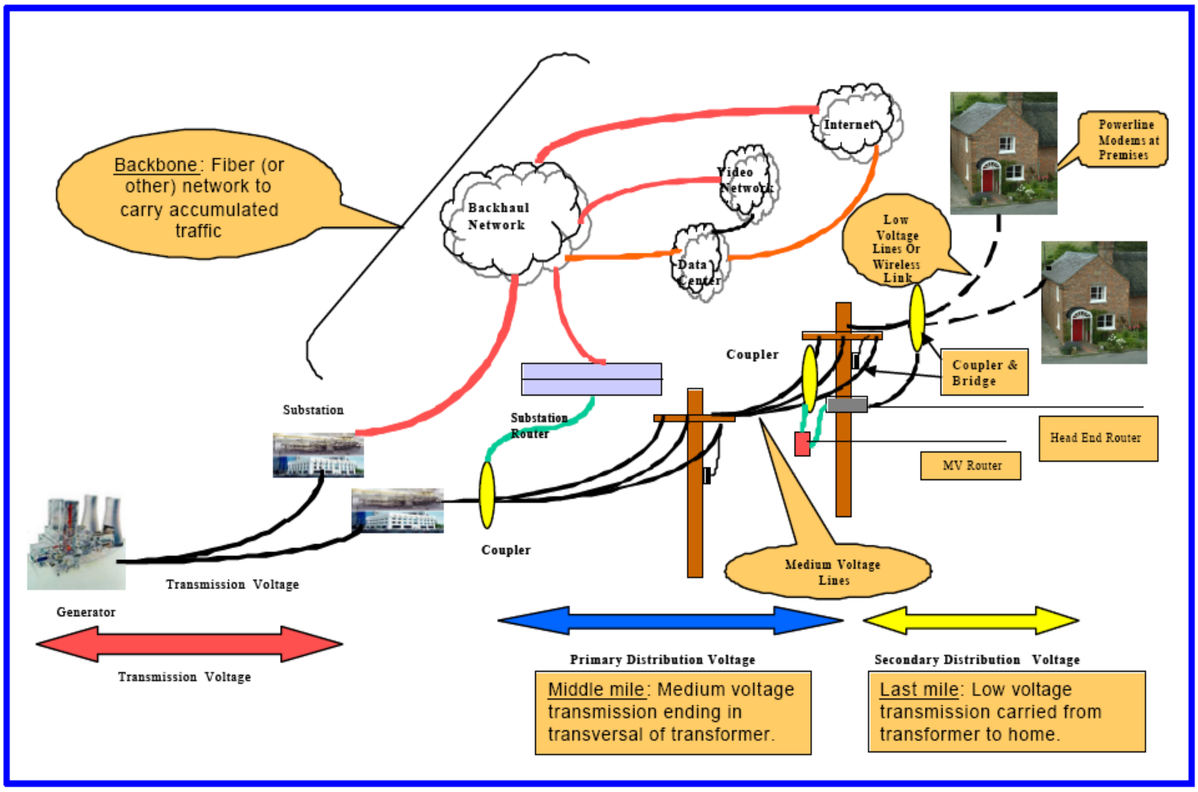


Figure 2 PLC Architecture Schematics.

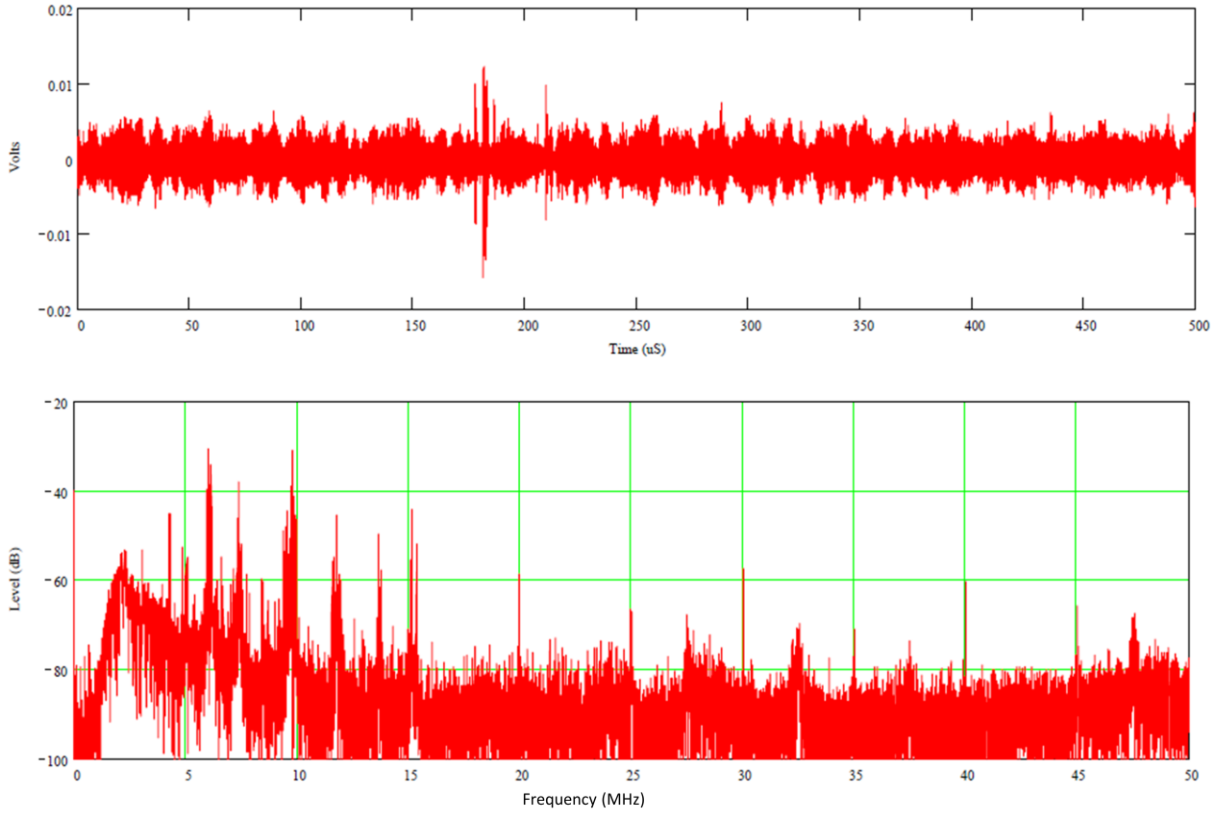
$$p(k) = P(X = k) = e^{-\lambda}\frac{\lambda^k}{k!} \quad k = 0, 1, 2, \ldots\ldots \quad (2)$$

The probability density function (PDF), $p(v)$ of the noise amplitude v is given as (Korki et al., 2011)

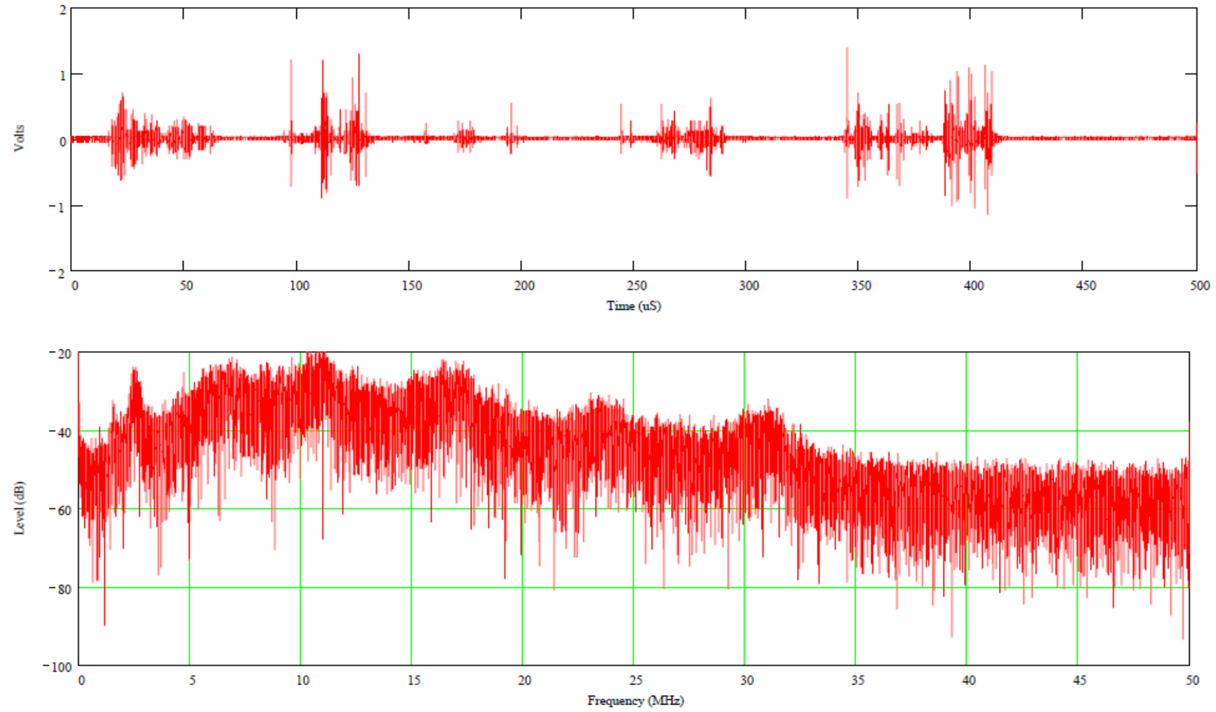
$$p(v) = \sum_{k=0}^{\infty}\frac{e^{-A}.A^t}{t}.\frac{1}{\sqrt{2\pi}.\sigma_t}.\exp\left(\frac{-v^2}{2.\sigma_t^2}\right) \quad (3)$$

where $\sigma_t^2 = P(t/A) + \Gamma/1 + \Gamma$. The parameters $P = \sigma_w^2 + \sigma_k^2$ is total noise power where σ_w^2 and σ_k^2 stand for Gaussian and impulsive noise power respectively, $\Gamma = \sigma_w^2/\sigma_k^2$, t is time of k arrivals and A is impulsive index.

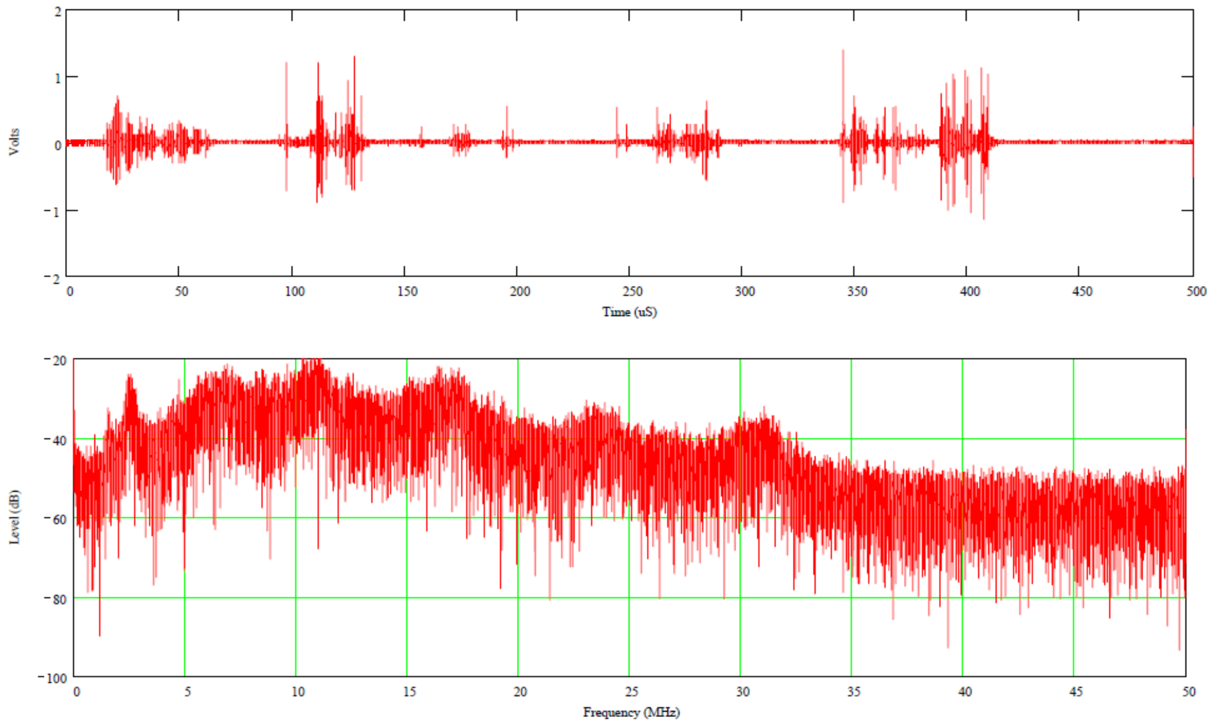
Impulsive noise are transient characterized uniformly distributed disturbances over the useful transmission system passband. They can be caused by voltage spikes in equipment, voltage changes on adjacent pairs in a copper cable, tones generated for network signaling, maintenance and test procedures, lightning flashes during thunderstorms, and a wide variety of other phenomena. As impulse noise is short in duration ($^1/_{100}$ of a second, or so), it has little effect on voice communications, but can cause bit errors in a data transmission. Three parameters defines the characteristics of the impulsive, which include; impulse duration, its amplitude and its inter-arrival time (time in-between two successive impulses). Impulsive noise duration is random and varies from some tens to hundreds of micro seconds, while its amplitude follows an exponential function.
Impulsive noise can be grouped into three (3) categories; 1, Periodic impulsive noise asynchronous to the mains frequency, its repetition rate is between 50 KHz to 200 KHz. This noise is often caused by switching power supplies; 2, Periodic impulsive noise, synchronous to the mains frequency. These are of short durations having its PSD varying inversely as frequency. Its repetition rate is of 50 Hz or 100 Hz. They are caused by power supplies operating synchronously with the mains cycle; 3, Asynchronous impulsive noise, this type of impulsive noise have duration of some microseconds up to a few milliseconds and they arrive randomly. Its PSD can reach values of more than 50 dB above the background noise.
Category 1 of the impulsive noise is a cyclostationary noise which remains stationary usually over periods of seconds and minutes or sometimes even hours. But categories 2 and 3 are time variant, varying between microseconds and milliseconds. Figure 2 shows the spectrum of these categories of impulsive noise. When these impulsive noises occur, noise PSD is perceptibly higher and this can lead to bit or burst errors in broadband data transmission.


Volts
Time (uS)
Level (dB)
Frequency (MHz)

(a)


Volts
Time (uS)
Level (dB)
Frequency (MHz)

(b)



(c)

Figure 3 Impulsive noise spectrum categories (a) Periodic Impulsive Noise synchronous with the mains frequency (b) Periodic Impulsive Noise Asynchronous with the mains frequency, (c) Asynchronous Impulse Noise

3.0 Impulsive noise mitigation

Impulsive noise as described above poses the most severe threat to broadband signal transmitted on the power line network. This is so because the impulsive noise arrives randomly, spanning through microseconds to milliseconds, with a power spectral density (PSD) that is above the background noise. Owing to this characteristic, the impulsive noise has capacity to corrupt the signal being transmitted through power line network. Combating this noise in PLC will go a long way to achieving serenity of the power line used as its medium of propagation. Therefore, mitigating impulsive noise in PLC is a worthwhile activity.

4.0 Impulsive noise mitigation techniques in PLC

The different mitigation techniques were classified into four groups, namely; time domain, time/frequency domain, error correction code and other techniques. Time domain technique is a memoryless nonlinear technique where the signal's amplitude only changes according to a specified threshold without changing the phase, mitigation of impulsive noise is carried out on the received time domain signal before the demodulation FFT operation of the OFDM. Time/Frequency technique is a method of mitigating impulsive noise on the received signal at both before FFT demodulation and after FFT demodulation of the OFDM system. Error correction code technique is the application of forward error correction code by adding redundancy bits to the useful data bits for detection and possibly correction of error occurring during transmission. Other mitigation techniques reviewed are sparse Bayesian learning technique, recursive detection technique and PLC-DMT (Discrete multi-tone transceiver).

4.1 Time domain mitigation technique

This technique assumes that the amplitudes of the impulsive noise is conspicuously greater than the OFDM signal amplitude. Therefore, amplitudes of the sampled signals greater than a defined threshold value are assumed to be affected by impulsive noise. The reviewed papers, (Korki et al., 2011), (Y. Kim, Kim, Oh, Kim, & Kim, 2008), (Ndo, Siohan, Member, & Hamon, 2010) and (K. S. Al-mawali et al., 2009) in this study mitigated impulsive noise in PLC system by implementing noise amplitude clipping, blanking or a combination of both. Amplitude clipping is the change in amplitude of a signal according to specific threshold without changing its phase while amplitude blanking is nulling/setting to zero, of a signal’s amplitude according to a specific threshold while not altering its phase. Figure 1 illustrates the different modes of time domain techniques, T_c is clipping threshold, T_b is blanking threshold. Hence, any sample having an amplitude lower than the threshold are considered to be correct OFDM and are passed unchanged, while those above the threshold are clipped to T_c. In blanking, every sampled signal having amplitudes below or equal to the threshold value, T_b, is passed and those above it are blanked off (replaced with zero). In the combine clipping/blanking method, T_c was chosen to be less than T_b, so samples having amplitudes lower than the threshold, T_c, are passed while samples whose amplitudes are below the blanking threshold, T_b, but above the clipping threshold are clipped to T_c, and samples having magnitudes above T_b are blanked off (set to zero). The choice of this technique was due to its simplicity in practical applications for impulsive noise mitigations.

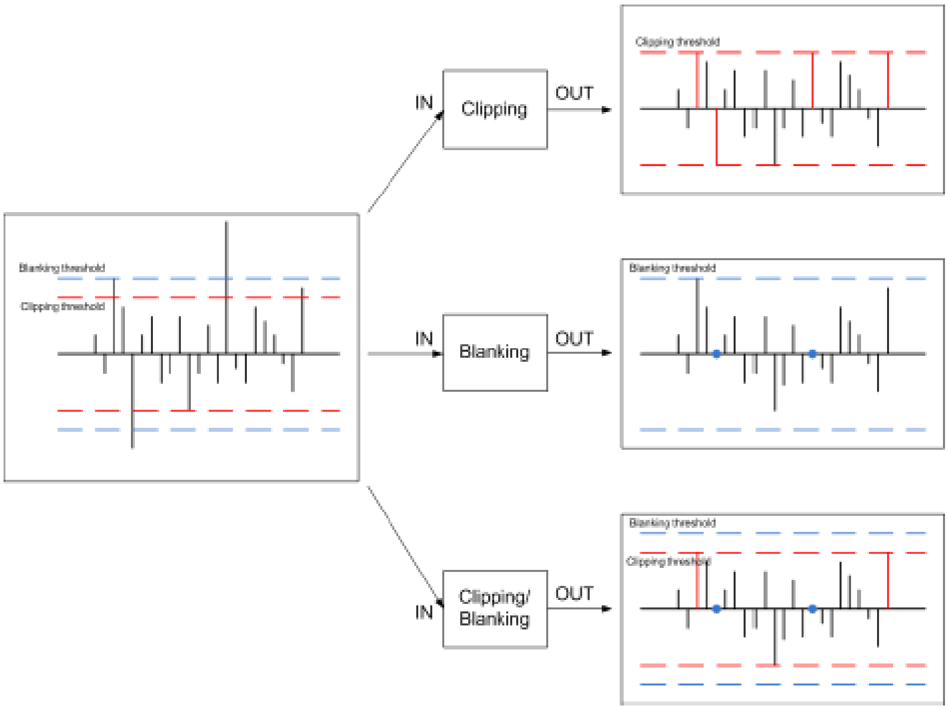


Figure 4 Time domain impulsive noise mitigation schematics (clipping, blanking & clipping/blanking)

Various methods of time domain technique were adopted by different Authors to mitigate impulsive noise in PLC. A signal level limiter was implemented in Kim et al. (Y. Kim et al., 2008) to mitigate impulsive noise in coherent M-ary PSK and different MPSK of PL system. Signal level limiter, a simple non-linear function in the received time domain was carried out at three estimation scenarios, namely, least square, perfect channel and one-tap equalized channel estimations. The method achieved a 1 dB improvement in SNR (figure 5) over the one-tap equalization channel estimation, although the improvement is small.

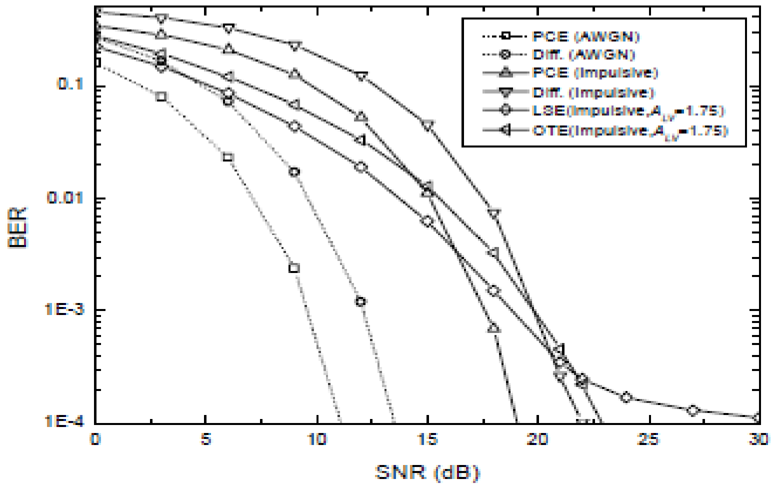


Figure 5 Kim et al Impulsive noise mitigation result (Y. Kim et al., 2008)

Ndo et al. (Ndo et al., 2010) achieved a 2.9 dB and 5 dB SNR saving in the two test scenarios considered, heavily and weakly disturbed respectively as shown in figure 6, using an automatic adaptive procedure of mitigation. This method involves the derivation of Bernoulli Gaussian (BG) noise parameters and clipping threshold updating according to the BG noise parameter value. The achievement recorded was with an increase in overhead in circuit complexity.

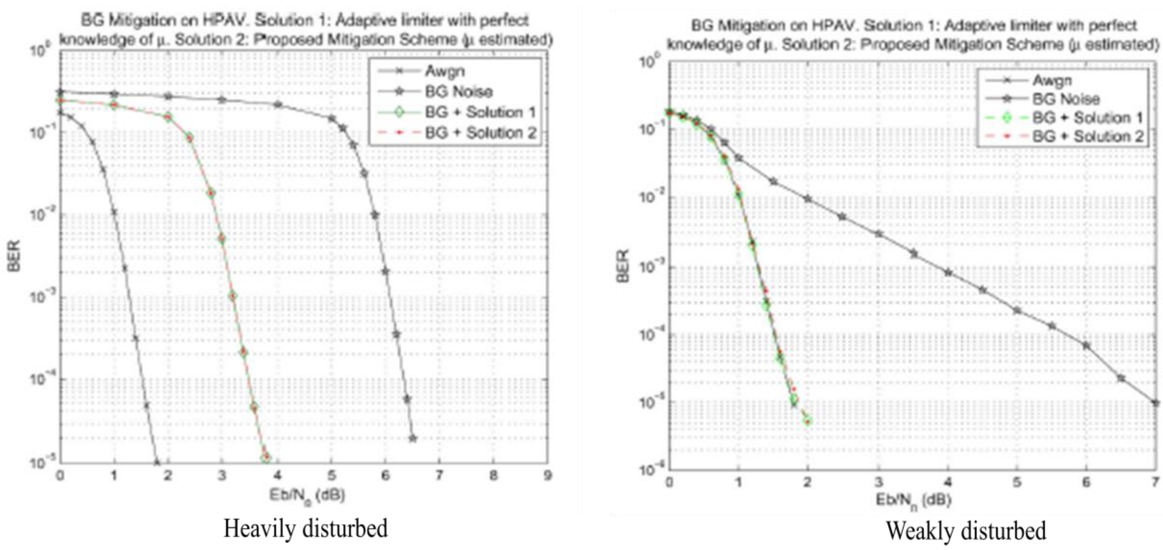


Figure 6 Ndo et al. Impulsive noise mitigation result (Ndo et al., 2010)

Clipping and blanking non-linearity was combined in (Korki et al., 2011) to reduce the effect of impulsive noise in narrowband region. Optimal threshold values were determined from BER curve as a function of a set threshold values for clipping, T_1 and blanking, T_2. Figure 7 shows that the optimal threshold for the combined clipping and blanking performed better than the fixed one reaching a saving of 1.5 dB in SNR.

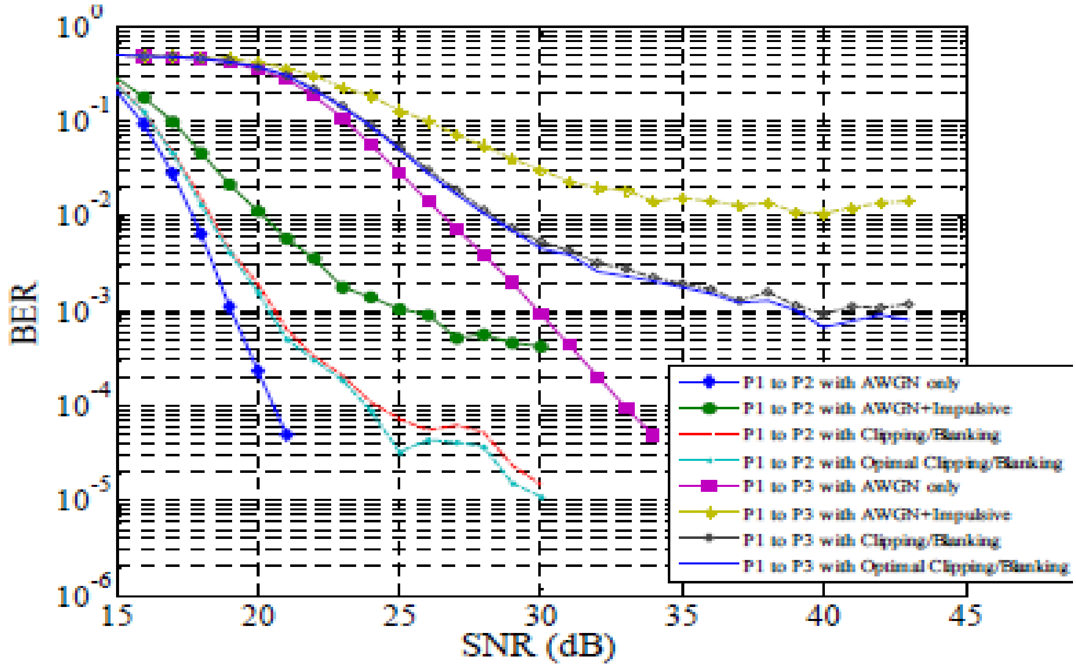


Figure 7 Mehdi et al. Impulsive noise mitigation result (Korki et al., 2011)

Three impulsive noise scenarios, namely, heavily disturbed, medium disturbed and weakly disturbed were mitigated in Al-mawali et al. (K. S. Al-mawali et al., 2009) using clipping, blanking and a combination of both. Optimal thresholds values of all the three methods for the test scenarios were determined and implemented. The combined method (clipping/blanking), achieved 5 dB SNR improvement over other methods in the heavily disturbed test condition (figure 8). Al-mawali et al.'s (K. S. Al-mawali et al., 2009) method, being the best performed method was selected in the time domain technique.

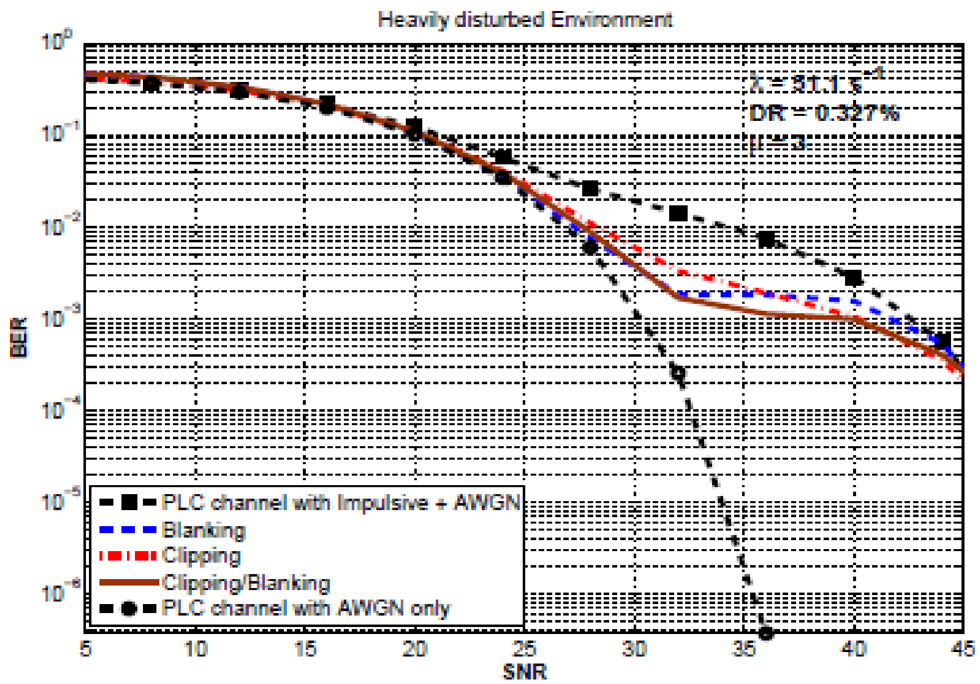


Figure 8 Al-mawali et al. Impulsive noise mitigation result (K. S. Al-mawali et al., 2009)

4.2 Time and frequency domain (TFD) technique

Another technique of impulsive noise mitigation in PLC is the combined mitigation at both time and frequency domains.

Frequency domain (FD) mitigation is applicable only in situations when signal is to be classified/detected alongside wit parameter estimation, with the objective of compensating for average noise effect on the sampled signal. In this domain, the noise effect varies in the mean of the signal's power spectrum. Mitigation in frequency domain takes place after the OFDM demodulation and an under an assumption of ideal channel estimation. It involves the following steps;

- estimation of frequency domain representation of impulsive noise corrupted by AWGN.
- a noise compensator then estimates the number of samples affected by the impulsive noise and reconstruct the impulsive noise vector using a peak detector.
- the estimated impulsive noise is then subtracted from the equalizer output

Therefore, FD impulsive noise mitigation entails the suppression of the impulsive noise after demodulation and eventual channel equalization of the received signal. Channel equalization is done to compensate for linear distortion which affects a signal while being transmitted.
Time domain mitigation is as explained in section , comprising the activities of clipping, blanking and a combination of both.
The combination of both time and frequency domain is governed by where each of the mitigation takes place. The time domain mitigation takes place before the OFDM demodulation while the frequency domain is after the OFDM demodulation as shown in figure 9.

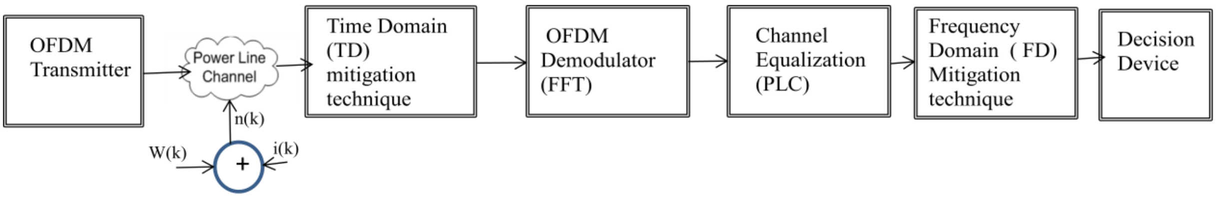


Figure 9 Time/Frequency Domain (TFD) mitigation configuration

The combined amplitude clipping and channel equalization TFD method was used in (Y. C. Kim, Bae, Kim, & Member, 2011).
The amplitude clipping network was used before the equalizer which comes before the OFDM demodulator. The equalizer was used to compensate for the PLC channel. Zero forcing was used for the equalization over three different modulation schemes, BPSK, QPSK, and 16QAM.
A simulation result of the BER performance of the mitigation scheme on coded and un-coded PLC system is as presented in figure 10. On the coded PLC system curve, an SNR improvement of 0.5 dB - 0.6 dB at 10^{-3} BER was obtained with the mitigation, while 0.4 dB– 0.7 dB was achieved by the scheme for the coded PLC system. This improvement in SNR is very small.

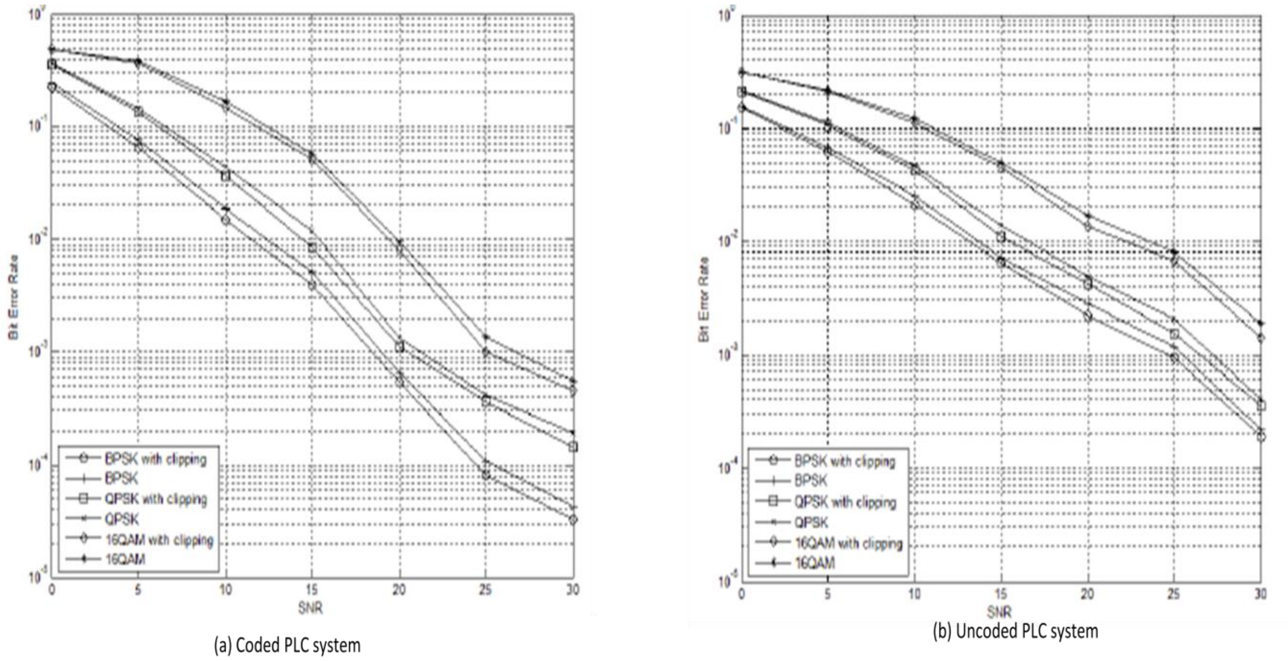


Figure 10 BER performance of time/frequency domain mitigation (Y. C. Kim et al., 2011

Al-mawali et al. (K. Al-mawali, Sadik, Hussain, & System, 2008) in their system, reduced impulsive noise in the OFDM by passing the OFDM signal through a time domain pre-processor, containing a combination of clipping/blanking non-linearity. The choice of this combination is for its better performance over clipping and blanking non-linearities. Frequency suppression technique was then applied on the OFDM signal after channel equalization and demodulation by means of DFT to further improve the impulsive noise mitigation. Three test scenarios were also considered, heavily, medium and weakly disturbed conditions. About 5dB SNR improvement was achieved with the proposed scheme over the combination of clipping/blanking time domain non-linearity alone as depicted in figure 11 (heavily disturbed). The scheme with the best performance improvement in this category for heavily disturbed scenario is (K. Al-mawali et al., 2008)

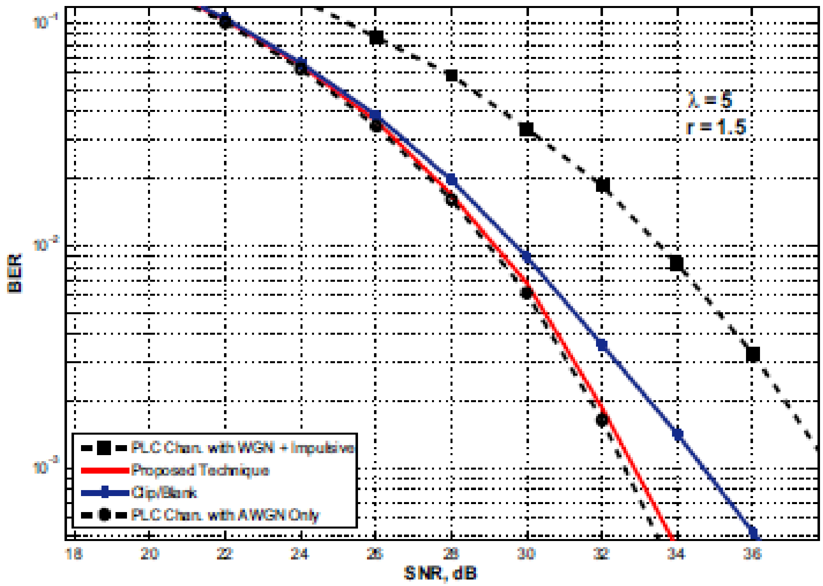


Figure 11 BER performance for time/frequency domain impulsive noise mitigation (K. Al-mawali et al., 2008)

4.3 Error correction codes (ECC) techniques

Effective channel coding has a high capacity for combating impulsive noise and other channel impairment in the PLC. Forward error correction, having to do with adding redundancy bits to the useful data bits, is implemented in this technique. Redundancy bits are bits which carries no information but which is added to the information-carrying bits of a character or stream of characters to determine their accuracy. Figure 12 shows a sample of redundancy bits deployment.

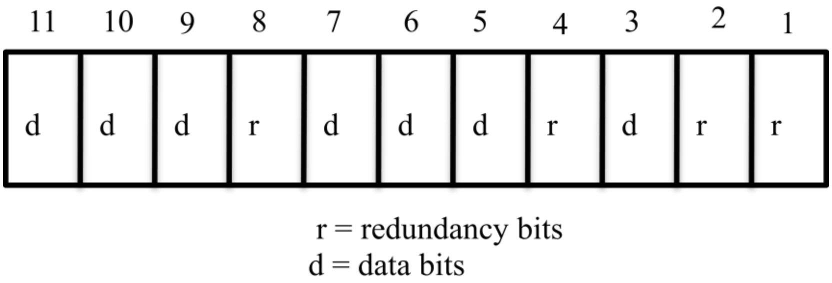
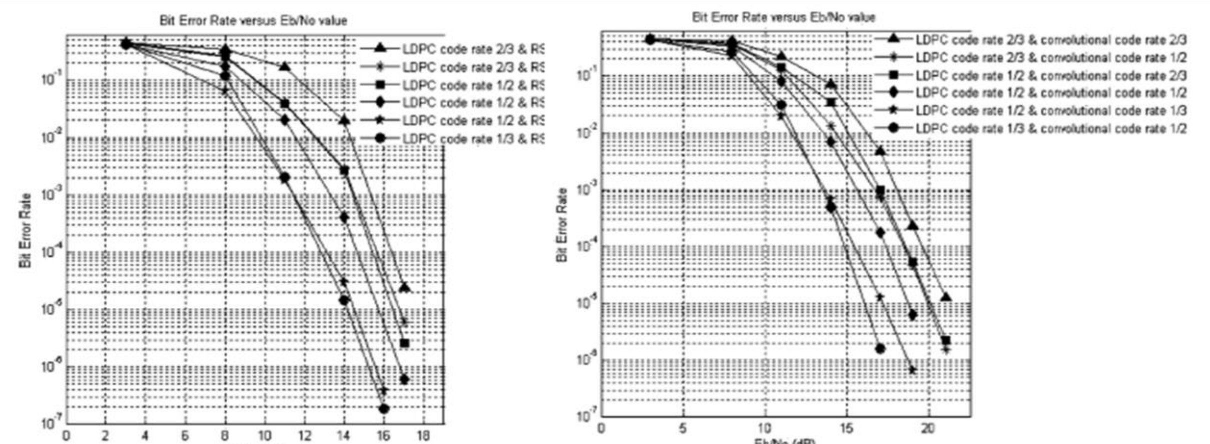


Figure 12 Redundancy bits positioning in Hamming codes

These redundancy bits are then used at the receiver to detect and possibly correct the errors occurring during data transmission, thereby avoiding reduction in useful data rate. There are several coding methods that can be implemented for the mitigation of impulsive noise.

Irregular Quassi Cyclic-Low Density Parity Check (QC-LDPC) codes were used to mitigate impulsive noise in (Andreadou & Pavlidou, 2010). This code was combined with Reed Solomon and convolution codes. Sum-product decoding algorithm was used to enable the operation when the QC-LDPC/Reed Solomon and QC-LDPC/Convolution codes combinations were used as outer coding scheme in a PLC channel scenario. Simulation for various code rates showed that a better performance was achieved with QC-LDPC/Reed Solomon code combination than for the QC-LDPC/Convolution code combination, achieving about 1.8 dB improvement at a BER of 10^{-4} as shown in figure 13.

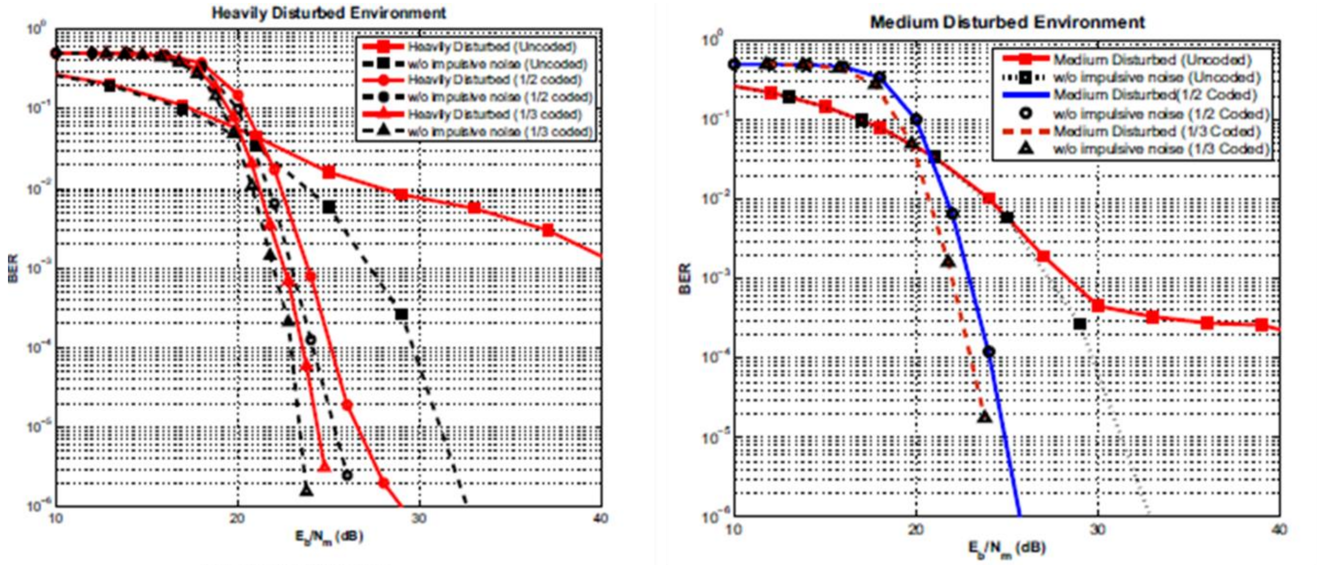


(a): QC–LDPC and RS codes of various code rates, with LDPC as the outer decoding scheme.

(b): QC–LDPC and convolutional codes of various code rates, with LDPC as the outer decoding scheme.

Figure 13 BER performance for QC-LDPC/Reed Solomon and QC-LDPC/Convolution codes (Andreadou & Pavlidou, 2010).

A system that implemented a convolution coding with interleaving at the transmitter end and viterbi decoding and de-interleaving at the receiving end of a PLC system was presented in (Al-Mawali & Hussain, 2009). Generator polynomials at 1⁄2 and 1⁄3 code rates respectively were used to encode the data. These data were then randomly interleaved and mapped into QPSK symbols. At the receiver, the data were de-mapped and viterbi decoded. Simulation was performed for three different scenarios; heavily, medium and weakly disturbed scenarios. Result showed that 15db improvement was achieved in the heavily disturbed environment while for medium and weakly disturbed environment, impulsive noise was completely eliminated as shown in figure 14 (heavily and weakly disturbed).



(a): Heavily disturbed

(b): Medium disturbed

Figure 14 BER performance of bit-interleaved coded OFDM-based PLC system (Al-Mawali & Hussain, 2009)

While considering the heavily disturbed environment in this category of impulsive noise mitigation technique (ECC), (Al-Mawali & Hussain, 2009) is selected as the best performed method in terms of BER improvement.

4.4 Other impulsive noise mitigation techniques

Under this category, three methods were used in the mitigation of impulsive noise in PLC. These include sparse Bayesian learning method, recursive detection method and PLC-DMT (Discrete multi-tone transceiver) method. A non-parametric (not needing training) asynchronous impulse noise mitigation algorithm, which is an extension of compressed sensing (CS) algorithm into Sparse Bayesian Learning (SBL), applied to all impulse noise scenarios in PLC was presented by Lin et al. (Lin, Member, & Nassar, 2013). Sparse Bayesian Learning is a learning approach for solving the linear regression problems and its outcome is sparse weight vector estimation. A maximum a posteriori (MAP) estimate was obtained after which the likelihood of observation is expressed by the SBL's imposition of parameterized Gaussian. This leads to the computation of the maximum likelihood estimation (MLE). The SBL was further used to estimate the impulsive noise using null and pilot tones. The proposed method, as shown in figure 15, performs better to the tune of 10 dB SNR over conventional OFDM receivers in the cyclostationary impulsive noise for a null tone. In all tones, addition of 2 – 5 dB gain was achieved.

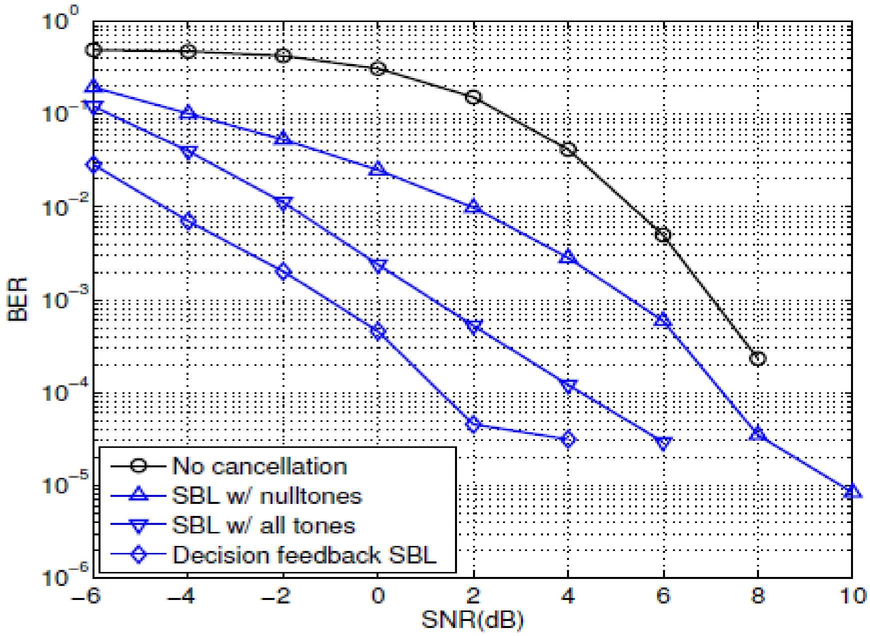


Figure 15 SBL BER performance in cyclostationary impulsive noise (Lin et al., 2013)

The work of (Zahedpour, Feizi, Amini, Ferdosizadeh, & Marvasti, 2008) focused on removing additive impulse noise using the zeros in the Discrete Fourier Transform (DFT) domain. In this model, there is need for reconstruction of each impulsive noise, this is done with two information; location and amplitude of the impulsive noise. The method implemented is called Recursive Detection Estimation (RDE). This system consists of noise detector and signal estimator block. Detection was done based on difference of the sample and the average of its neighbours. A none detection of a corrupt signal is considered a missed detection and it leads to a false alarm. So a binary mask is generated, zero, if impulsive noise is detected and one if otherwise. Iterative method on the other hand removes the impulsive noise by using the binary mask generated in the detection block and reproducing the original signal, this signal is reconstructed faster than noise. The half capacity (one fourth of the number of DFT zeros of the signal) had SNR improvement over the full capacity (half of the number of the DFT zeros of the signal) over different steps of RDE, when hard-limiting and low-pass processes were repeated in simulation as shown in figure 16.

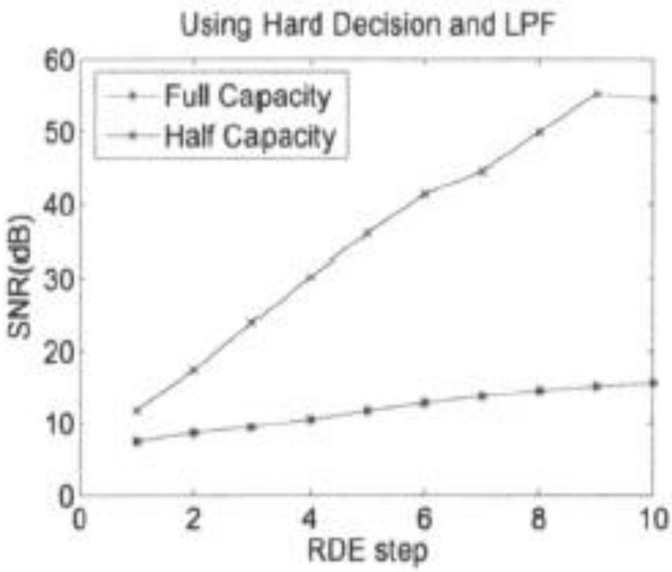


Figure 16 Impulsive noise cancellation using hard-decision and simple detector (Zahedpour et al., 2008)

Two methods/apparatus were implemented by Ribeiro et al. (Ribeiro, Lopes, Romano, Member, & Duque, 2006) to model the transfer characteristics of the power line, these are bottom up and top down. The OFDM symbol is then computed by passing the OFDM transmitter vector through an N x N Inverse Discrete Fourier Transform (IDFT) matrix. The strategy implemented is a process intended at reducing signal noise power as this will increase the SNR of the system and thus increase the bit-rate capacity. The technique is a modified PLC-DMT, where a technique evolving from computational intelligence is used to mitigate the non- gaussian noise in the PLC. Multilayer Perception Neural Network (MLPNN) as a particular case of a computational intelligence, was used for the reduction of non-gaussian noise, this choice was due to the neural network's ability to learn nonlinear features from the data available and thus remove corrupted signal from the non-linear component. PLC-DMT shows that MLPNN successfully reduce the impulse noise at the output of the power line, yielding a background noise PSD of -120 dB/Hz, impulse noise PSD of -90 dB/Hz when the transmitting signal PSD is -70dB/Hz. The obtained simulation results reveals that MLPNN results in an SNR increase, with an improvement of 5 dB and figure 17 shows its bits rate improvement over the PLC-DMT. The method presents a complexity when compared with other computational techniques of optimization.

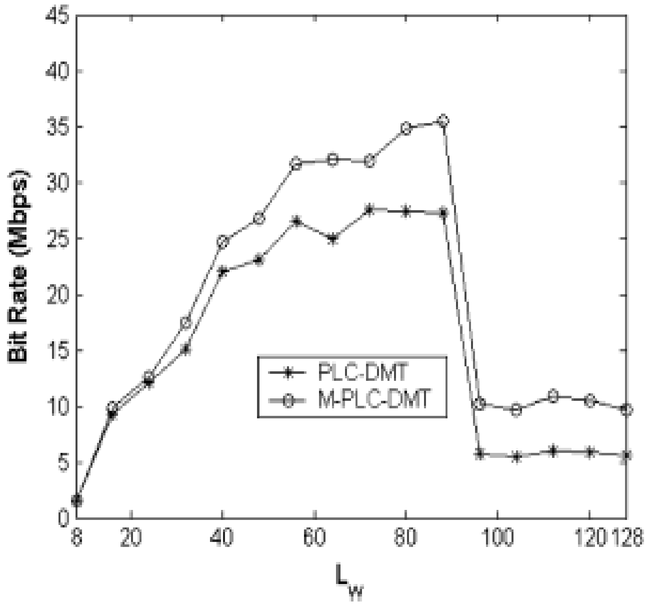


Figure 17 M-PLC-DMT and PLC-DMT performances in terms of the length of a shortening equalizer for PL channel (Ribeiro et al., 2006)

In this category, [14] was selected as the scheme with the best BER's performance.

5.0 Performance comparison

The best performing scheme in each of the different impulsive noise mitigation categories were selected and the BER vs SNR curves were compared. Figures 18-21 shows these curves. A benchmark of 10^{-3} BER was chosen for the comparison. Figure 18 shows that an SNR of about 7 dB improvement was achieved with the time domain technique impulsive noise mitigation. For the time/frequency domain technique depicted in figure 19, about 11 dB SNR was saved. The two convolution codes implemented, provided an improvement in SNR to the tune of 14 dB and 16 dB respectively as shown in figure 20. An examination of figure 21 shows that the selected scheme for other techniques renders close to 8 dB SNR improvement in the mitigation of impulsive noise. The description of the SNR improvements of the various impulsive noise mitigation techniques is shown in figure 22.

6.0 Conclusion

Impulsive noise is the noise that poses the most severe threat to digital signal in Power Line Communication system, as it comes in burst form, thus corrupting the digital signal transmission. Mitigating these impulse noises will a great deal render the power line a more decent medium for broadband data transmission. This will enhance the acceptability of the medium, since it is easy to install and readily available. Different methods for the mitigation of impulsive noise in Power line Communication system have been reviewed under four categories. Each of these techniques reduces the effect of this noise in the PLC system while a technique eliminates its effect completely. BER vs SNR comparison of the entire reviewed techniques was carried out with 10^{-3} BER as reference. Although some of these achievements were with tradeoffs for circuit complexity and cost of construction. The error correction code (ECC) method offers the best mitigation, presenting almost an outright elimination of the noise under the conditions of medium and weakly disturbed environment.

This paper x-rays the methods deployed in the mitigation of impulsive noise in PLC, bringing to bare the fact that impulsive noise can be vehemently mitigated in PLC. The problem encountered by signals transmitted through the power line network is not just impulsive noise as identified in section 1. Therefore future of impairment mitigation in PLC still leaves a lacuna in the PLC channel capacity enhancement. Thus, solving the challenges posed by the power line branching, the length of the line and the line mismatch caused by the load at the far end are areas of research calling for attention.

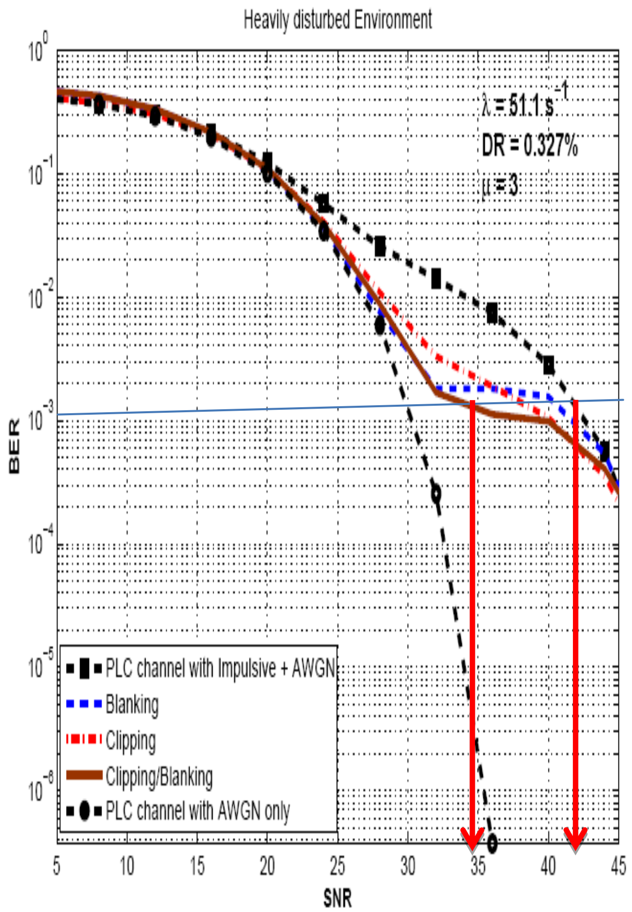


Figure 18 Time domain Technique

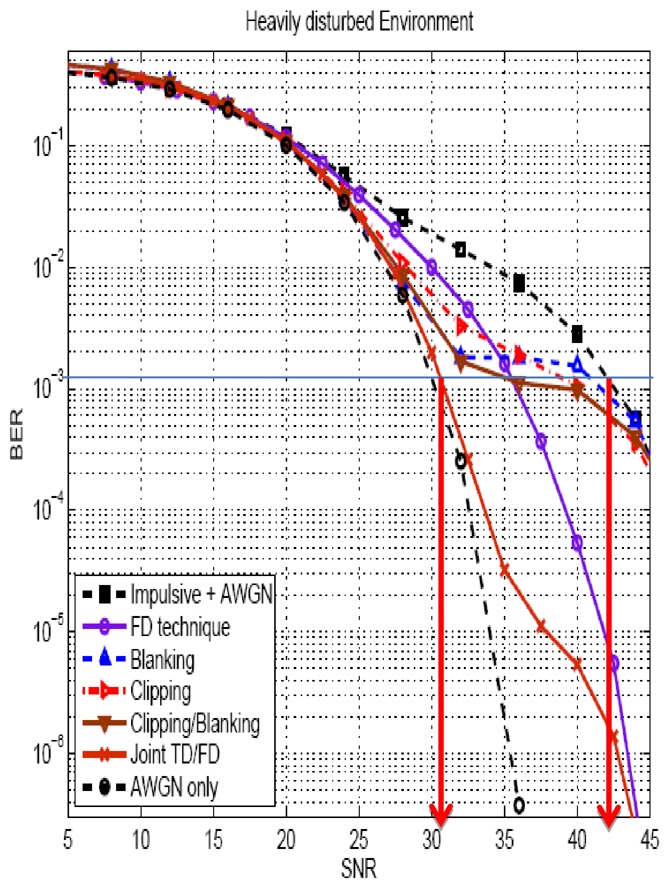
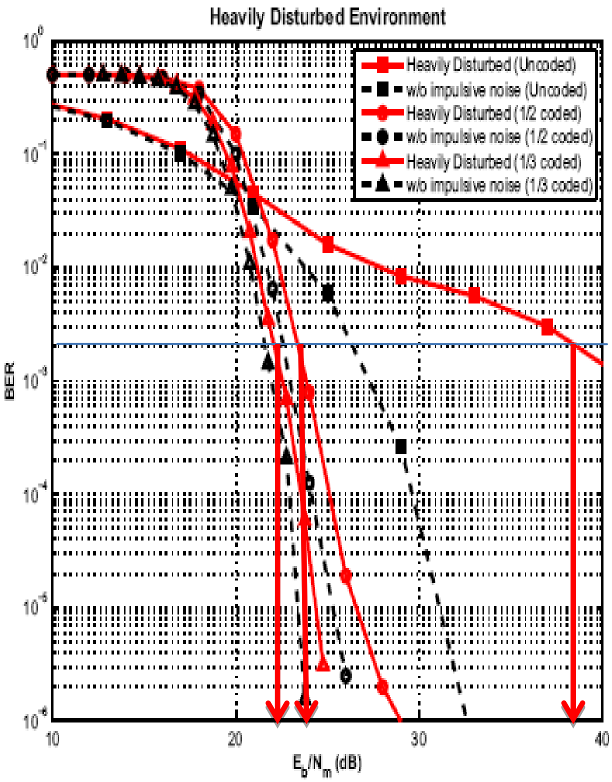


Figure 19 Time/frequency domain Technique



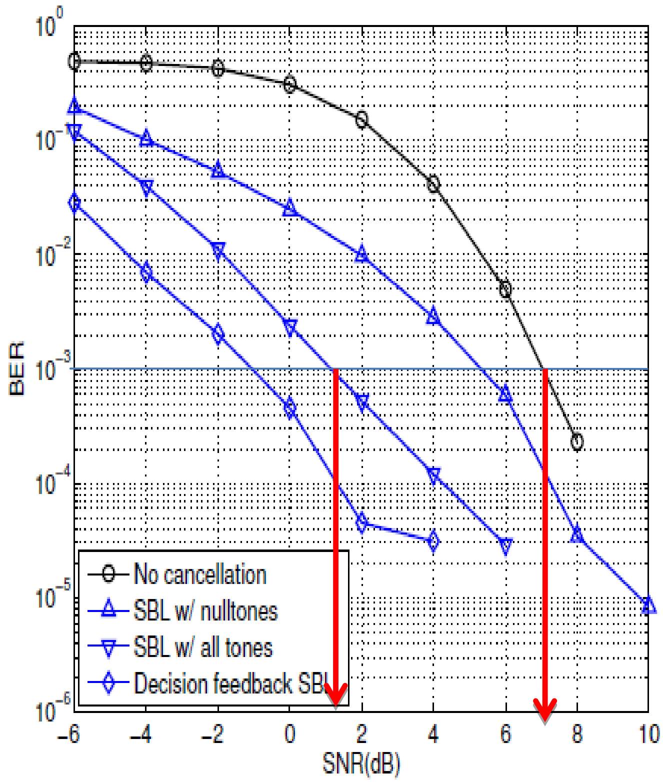


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Figure 20 Error correction code technique

Figure 21 Other techniques

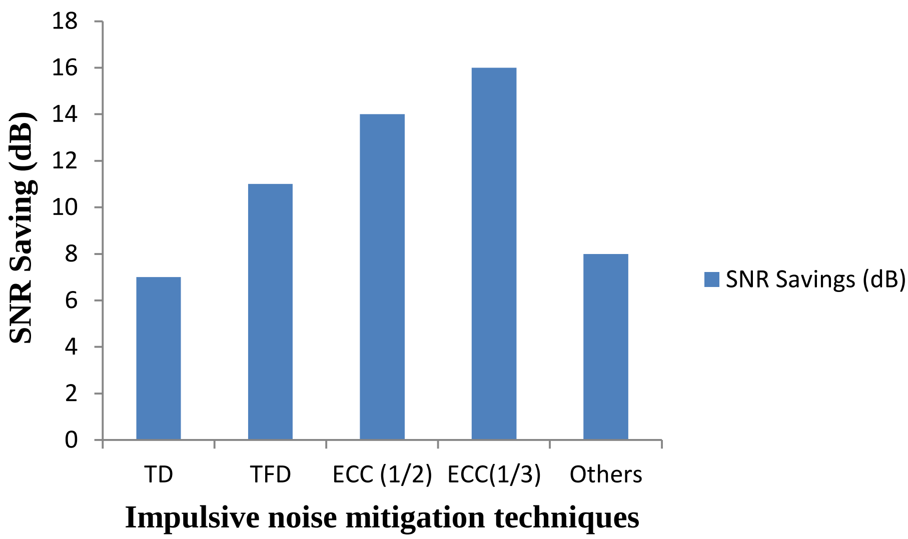

Figure 22 Techniques performance comparison

References

Al-Mawali, K. S., & Hussain, Z. M. (2009), "Performance of bit-interleaved coded OFDM in power line communications with impulsive noise", 2009 International Conference on Advanced Technologies for Communications, 49–53. doi:10.1109/ATC.2009.5349345

Al-mawali, K. S., Sadik, A. Z., Hussain, Z. M., & System, A. O. (2009), "Time-Domain Techniques for Impulsive Noise Reduction in OFDM-Based Power Line Communications: A Comparative Study", Proceedings of the 2009 International Conference on Communication, Computer and Power (ICCCP'09), 1 – 5.

Al-mawali, K., Sadik, A. Z., Hussain, Z. M., & System, A. O. (2008), "Joint Time-domain / Frequency-domain Impulsive Noise Reduction in OFDM-based Power Line Communications", Australasian Telecommunications Networks and Applications Conference, ATNAC 2008., 138–142.

Andreadou, N., & Pavlidou, F. (2010), "Mitigation of Impulsive Noise Effect on the PLC Channel With QC – LDPC Codes", IEEE Transactions on Power Delivery, 25(3), 1440–1449.

Cort, A., Luis, D., & Ca, F. J. (2009), "Analysis of the Periodic Impulsive Noise Asynchronous with the Mains in Indoor PLC Channels", IEEE International Symposium on Power Line Communications and Applications, 26 – 30.

Guillet, V., Lamarque, G., & Ravier, P. (2009), "Improving the power line communication signal-to-noise ratio during a resistive load commutation", Journal of Communications, 4(2), 126–132.

Hashmat, R., Pagani, P., Zeddam, A., & Chonavel, T. (2011), "A Channel Model for Multiple Input Multiple Output In-home Power Line Networks", IEEE International Symposium on Power Line Communications and Applications, 35–41.

Katayama, M., Yamazato, T., & Okada, H. (2006), "A Mathematical Model of Noise in Narrowband Power Line Communication Systems", IEE Journal on Selected Areas in Communication, 24(7), 1267–1276.

Kim, Y. C., Bae, J. N., Kim, J. Y., & Member, S. (2011), "Novel Noise Reduction Scheme for Power Line Communication Systems with Smart Grid Applications", Internatonal Conference on Consumer Electronics (ICCE), 791–792.

Kim, Y., Kim, K., Oh, H., Kim, K., & Kim, S. (2008), "Mitigation of effect of impulsive noise for OFDM systems over power line channels", 2008 IEEE International Symposium on Power Line Communications and Its Applications, 386–390. doi:10.1109/ISPLC.2008.4510459

Korki, M., Hosseinzadeh, N., Vu, H. L., Moazzeni, T., & Foh, C. H. (2011), "Impulsive noise reduction of a narrowband power line communication using optimal nonlinearity technique", 2011 Australasian Telecommunication Networks and Applications Conference (ATNAC), 1–4. doi:10.1109/ATNAC.2011.6096646

Lin, J., Member, S., & Nassar, M. (2013), "Impulsive Noise Mitigation in Powerline Communications Using Sparse Bayesian Learning", IEEE Journal on Selected Areas in Communications, 31(7), 1172 – 1183.

Ndo, G., Siohan, P., Member, S., & Hamon, M. (2010), "Adaptive Noise Mitigation in Impulsive Environment : Application to Power-Line Communications", IEEE Transactions on Power Delivery, 25(2), 647–656.

Ribeiro, M. V, Lopes, R. R., Romano, J. M. T., Member, S., & Duque, C. A. (2006), "Impulse Noise Mitigation Based on Computational Intelligence for Improved Bit Rate in PLC-DMT", IEEE Transactions on Power Delivery, 21(1), 94–101.

Tsakiris, S. I., Salis, A. D., & Uzunoglu, N. K. (2009), "Performance of OFDM Systems for Broadband Power Line Communications Under Low Signal Strength", Microwave Review, 9(2), 41–46.

Yousuf, M. S., Rizvi, S. Z., Arabia, S., & El-shafei, M. (2007), "Power Line Communications : An Overview – Part II", 4th International Conference on Innovations in Information Technology, IIT '07, 218 – 222.

Zahedpour, S., Feizi, S., Amini, A., Ferdosizadeh, M., & Marvasti, F. (2008), "Impulsive noise cancellation using CFAR and iterative techniques", 2008 International Conference on Telecommunications, 1–5. doi:10.1109/ICTEL.2008.4652641

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